Integrated Water Resources Management for Eastern Dry Zone of Sri Lanka

Study of Mundani River Basin

Babarande Guruge Thanura Lasantha[*]
(MEE15623)

Supervisor: Asso. Prof. Mohomad Rasmy[**]
Prof.Toshio Koike[***]
Dr. Duminda Perera[****]

ABSTRACT

Eastern Dry Zone of Sri Lanka is vulnerable to extreme floods and droughts. This paper provides the analyses of hazard in both drought and flood cases using rainfall and runoff as major concerns. Mundani Aru Basin is selected as the pilot study area, to propose new Integrated Water Resource Management (IWRM) practices. Accordingly past rainfall pattern was analyzed and the hydrology for past was estimated using Water and Energy Budget Based Rainfall Runoff Inundation (WEB RRI) model. Water Allocation Model for Irrigation (WAMI) was developed considering reservoir water budget and plant water budget. Rugam reservoir in present and future were virtually analyzed in WAMI under different IWRM practices. Those changes were economically evaluated and projected the anticipated income improvement. As the rainfall had been increasing in past (1990-2015), projection of climatology to see the future was done using Coupled Model Inter-comparison Project Phase 5 (CMIP5). It showed an increase in wetness while considerable increase in extreme rainfall. Extreme runoff will be twice in future. Consequently the upstream detention of flood water was calculated with required drainage sizes and tank operation rules. Both local and global climatology showed a considerable change after 2000 which implies the need of further projection of climatology using updated Global Climate Model (GCM) data beyond 2000. Orographic effect over climatology implies the necessity of dynamic downscaling using smaller grid scale to consider more undulations in Sri Lanka central mountains.

Key Words: IWRM, WEB RRI, IOD, Nino, CMIP-5

INTRODUCTION

Water hazards are the most dominant natural disasters in Sri Lanka. Department of Irrigation is the statutory organization empowered to deal with water hazards. Floods and droughts are frequent in Eastern dry zone due to its local topography and climate pattern. Dynamic pressure of vulnerability increased by 30 year war and presently in a war ceased situation the population and agriculture rise through an unsafe condition.

The rainy season is called as “Maha” and dry season is called as “Yala” which occur due to monsoon winds and orography of Sri Lanka. 5800 MCM of water is released to sea without use during the rainy season, while having a prolonged dry period in Eastern Dry Zone annually. Mundane Aru basin in Eastern Dry Zone, with size of 1,375 km^2 is considered in the study. In this basin two major reservoirs, three medium reservoirs and nearly 50 small tanks are existing to provide water to agriculture. Rugam reservoir is dominant among all due to its location and function. Department of Irrigation has proposed 3 major projects; 2 upstream reservoirs at Galode(75MCM) and Mahaoya(70MCM) and in downstream augmentation of Rugam from 23MCM to 65MCM .

THEORY AND METHODOLOGY

The research was carried out in targeting two main objectives.

1. Investigate the hydrological behavior of Eastern Dry Zone of Sri Lanka.

[*] Divisional Irrigation Engineer, Department of Irrigation , Sri Lanka
[**] Associate Professor GRIPS/ Senior Researcher, ICHARM
[***] Senior Professor Tokyo University/ Director ICHARM
[****] Lecturer/ Research Specialist, ICHARM

2. Propose new set of rule for effective water resources management and disaster risk reduction through IWRM

As shown in Figure 1, the main steps were followed. First the rainfall and runoff data of ground observation were collected from different sources and compiled. Those were compared and verify using Standardized Precipitation Index (SPI) and Standardized Runoff Index (SRI) for 25 years (1990-2015) for 3 stations. Then those were analyzed and studied the past climatology using statistical analysis and indices. That climatology was used in simulation using WEB RRI model and obtained the inflow for Rugam tank. The local climatology obtained from SPI was compared with global climatology obtained by Indian Ocean Dipole (IOD) and Nino Indices. The WAMI developed by coupling tank water budget and plant water budget was used in developing Rugam tank storage virtually and simulating for past 25 years. Future proposals to Rugam tank were virtually built in WAMI. Under different scenarios the performance of Rugam tank and its cultivation were checked. Accordingly the optimum IWRM were proposed. Those were economically evaluated and projected the anticipated income increment.

Figure 1: Flowchart of methodology

The projection of climatology using CMIP5 was conducted and checked constrains possible in future. Accordingly the hydrology and tank performance are projected and proposed the future IWRM. Those projections were economically evaluated.

Standardized Precipitation Index (SPI) and Standardized Runoff Index (SRI)

The SPI (McKee and others, 1993, 1995) is a powerful, flexible index that is simple to calculate and analyze wet periods and dry periods relative to rainfall pattern in specific region. This is based on the probability of precipitation for any time scale. (Guttman, 1994). In SPI computation, gamma probability density function is fitted to total precipitation frequency distribution of a station. Runoff also follows the same dynamics and therefore same probabilistic source code is used in SRI.

Indian Ocean dipole (IOD)

The Indian Ocean Dipole (IOD) is a phenomenon related with sea surface-atmosphere in the Indian Ocean. Irregular changes of sea surface temperature (SST) in the south eastern equatorial zone, western equatorial zone and Indian Ocean make anomalies in wind flows and sea currents. Those make changes in rainfall over the east Africa and Indonesian region

El-Nino and La- Nino (ENSO)

ENSO or the phenomenon of El Nino and La Nina occurs due to anomalies of SST in the central and eastern tropical Pacific seas to tropical Pacific seas. During an ENSO event, approximately one-third of the land areas of the globe have predictable effects. ENSO events often last for nearly one full year, and often begin during the April through July period and end during the same season of the following year. This enables climate forecasts for certain regions to be issued with lead times of 1 or more season. (Source: http://iri.columbia.edu/climate/forecast/tutorial2/)

Coupled Model Inter-comparison Project Phase 5 (CMIP5)

CMIP5 will notably provide a multi-model context for 1) assessing the mechanisms responsible for model differences in poorly understood feedbacks associated with the carbon cycle and with clouds, 2) examining climate “predictability” and exploring the ability of models to predict climate on decadal time scales, and, more generally, 3) determining why similarly forced models produce a range of responses. (Source: http://cmip-pcmdi.llnl.gov/cmip5/).

CMIP5 is consisting with 44 different data simulation models which are developed by different institutions under different scenarios. Those models are called GCMs run under different RCP (representative concentration pathways).

Water and Energy Budget Based Rainfall Runoff Inundation (WEB RRI) Model

Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012, Sayama et al., 2015a, Sayama et al., 2015b). This model is widely used in simulation of flood. However it doesn't give a clear picture in drought case as it doesn't analyze evapotranspiration and infiltration in great. Consequently use of "Water and Energy Budget Based Rainfall-Runoff-Inundation" (WEB RRI) model was considered.

The influence of solar energy (Both long wave and Short wave) over the movement of water between atmosphere and land surface are considered in WEB part. Hence the surface cover ,dynamic vegetation parameters which gives from leaf area index (LAI) and the fraction of photo synthetically active radiation (FPAR) absorbed by the green vegetation canopy, solar radiation data, land use data and soil classification data have to be upload. Then the sub surface water movement has to be considered. Basically RRI needs topographical data of the considered basin. Digitized topographical data can be downloaded from USGS HydroSHEDS website as a digital elevation model (DEM) in different scales. The downloaded DEM has to be modified to extract elevation data, flow direction data and flow accumulation data using Arc GIS tools. After adjusting the obtained DEM for ground conditions, it is ready to work on RRI.

Water Allocation Model for Irrigation (WAMI)

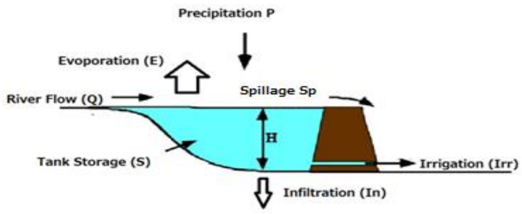


Figure 2: Reservoir storage model

$$Q = E + In + Irr + Sp + \Delta S - P$$

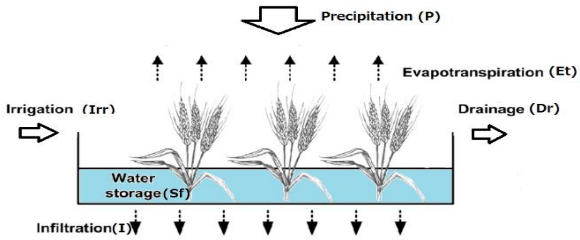


Figure 3: Plant water model

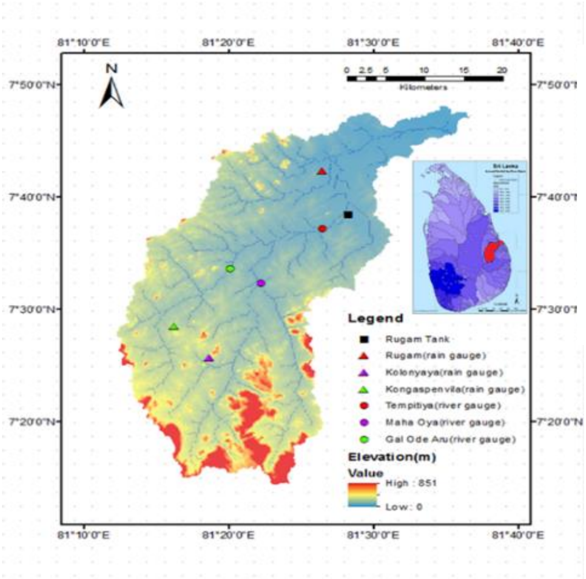
$$Irr = \left(Et + I + Dr + \Delta St - P\right) Ef \times Ec$$

The main purpose of irrigation tanks are to provide water to agriculture. Therefore the water resource management in irrigation system needs a knowledge of agriculture. With amalgamating the knowledge of agriculture (Plant Water Model-Figure 3) with climate and storage (Reservoir storage Model-Figure 2), a water allocation model for irrigation was developed. Spatial and Temporal allocation of water for irrigation governs by different parameters related to the crop, climate, soil and irrigation structure parameters. This model calculates the total water requirement for a command area for crop. In order to evaluate the whole water budget incorporated with irrigation, the simple water balance within the entire command area and the reservoir has to be set-up. If there are different soil types, different crops and different climatic zones, those have to be considered as divisions (blocks) incorporated in total command area. The total water demand for total command area is the summation of different water demands of each irrigation block. Here the convince efficiency Ef and field efficiency Ec is consider according to cultivation and irrigation method.

In economic analyses, an assumption made as the number of water deficit periods are proportion to percentage loss of harvest.

DATA

Data of ground measured rainfall and runoff were obtained from different sources. There are 3 rainfall and 3 river flow gauges as shown in Figure 4.



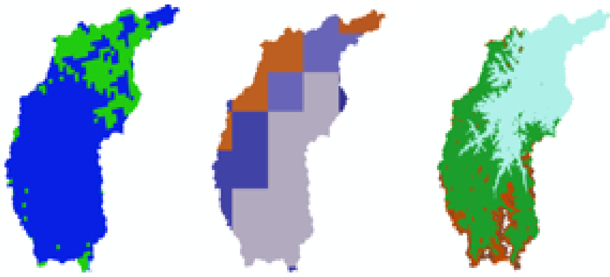


Figure 5: Satellite data-vegetation, soil classification and elevation

Figure 4: Gauge locations

Ground data for 25 years were compiled to use in analyses and simulations.

In simulation of hydrology global data set was used to obtain 15 arc second DEM, land use data and soil classification data (Figure 5).

RESULTS AND DISCUSSION

The SPI and SRI was plotted for last 25 years and checked the correlation. Accordingly it shows runoff is followed by rain. Thus the compiled data pass the verification and ready to use.

In the study of past climatology it was significant that the high wetness was in December and the wetness had been increasing. The driest was June and the dryness was remaining same. The intensity and frequency of occurrence of the rainfall was also been increasing which signals an increment of vulnerability in flood.The hydrology of the area for past was given from WEB RRI as Figure 6.

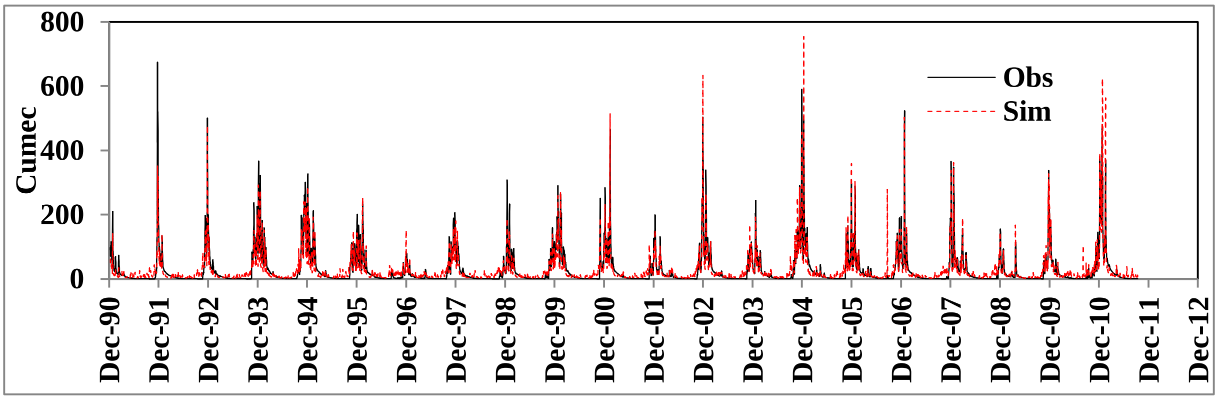


Figure 6: Model simulation and ground observed runoff at Rugam

The result compared with ground observed hydrology gave Nash coefficient 0.839 and RMSE 22.17. Thus the model runs satisfactorily in simulation.

The hydrology for past simulated in WAMI model for 23MCM Rugam tank and proposed 65MCM augmented Rugam tank. It gave the following results in economic analyses of different scenarios.

Table 1: Income change due to introduced IWRM practices to present Rugam tank

Type	Season	Days	Extent of Cultivation/Ha	Normal		Yala Advanced & Maha Same		Normal	Yala Advanced & Maha Same
				Dry	%Loss	Dry	%Loss	Harvest Income/$	Harvest Income/$
Normal	Yala	105	2096	34	0.32	4.50	0.04	1,771,619	2,507,714
	Maha	119	2620	0	0.00	6.50	0.05	3,275,000	3,096,113
3rd Crop	Intermediate	90	1000	90	1.00	90.00	1.00	0	0
W&D Mtd	Yala	105	2096	0	0.00	0.00	0.00	2,620,000	2,620,000
	Maha	119	2620	0	0.00	0.00	0.00	3,275,000	3,275,000
3rd Crop	Intermediate	90	1000	30	0.33	0.00	0.00	1,488,095	2,232,143

Table 2: Income change due to introduced IWRM practices to augmented Rugam tank

Type	Season	Days	Extent of Cultivation /Ha	Normal		Yala Advanced & Maha Same		Normal	Yala Advanced & Maha Same
				Dry	%Loss	Dry	%Loss	Harvest Income/$	Harvest Income/$
Normal	Yala	105	4800	33	0	13	0	4,114,286	5,257,143
	Maha	119	6000	7	0	28	0	7,090,336	5,735,294
3rd Crop	Intermediate	90	2500	90	1	90	1	0	0
W&D Mtd	Yala	105	4800	0	0	0	0	6,000,000	6,000,000
	Maha	119	6000	0	0	0	0	7,500,000	7,500,000
3rd Crop	Intermediate	90	2500	21	0	0	0	4,278,274	5,580,357

Accordingly if the Yala cultivation starts one month early to present practice with dry and wet irrigation method, ample amount of water to do an intermediate cultivation is saved in tank. If Mung bean is cultivated as the shown extent in above Table 1 and Maha land preparation in dry plough method gives an income increment in 61% for 23MCM tank and 70% to 65MCM tank (Table 2). Both structural and nonstructural improvements give 273% income increment in future.

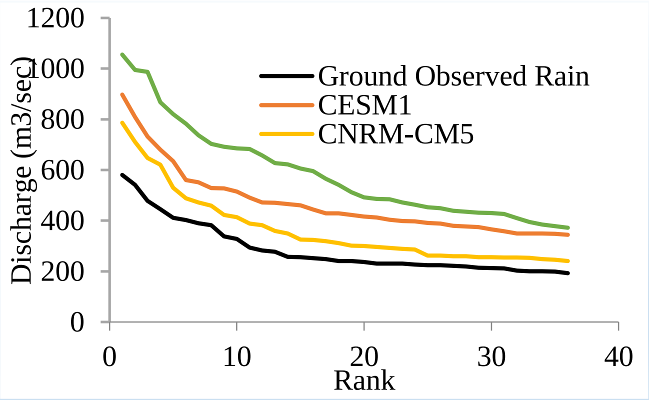


Figure 7: Extreme discharge (2056-2065)

However it was clear the spillage of reservoir is not considerably changed through this IWRM.

In future the wetness will increase. Therefore this IWRM practices for irrigation can be applied in future for drought case, but flood risk will be increased as shown in figure 7.

Accordingly in IWRM, different integrated flood risk management (IFRM) has to be adopted. Thereby upstream storages have to be increased at least by 100MCM, and the proposed and existing reservoirs have to be reduced their storage in order to accept high discharge. Thus at least 3 day advance rainfall forecasting has to be adopted while the downstream of each reservoir have to be improved to flow the spillage as shown in Table 3.

Table 3: Required flood detention and spillage

Reservoir	Capacity (MCM)	Required Downstream Flow Capacity (Cumec)
Rugam	65	192.90
Galode	70	135.03
Mahaoya	75	144.68
Rabakenoya	55	106.10

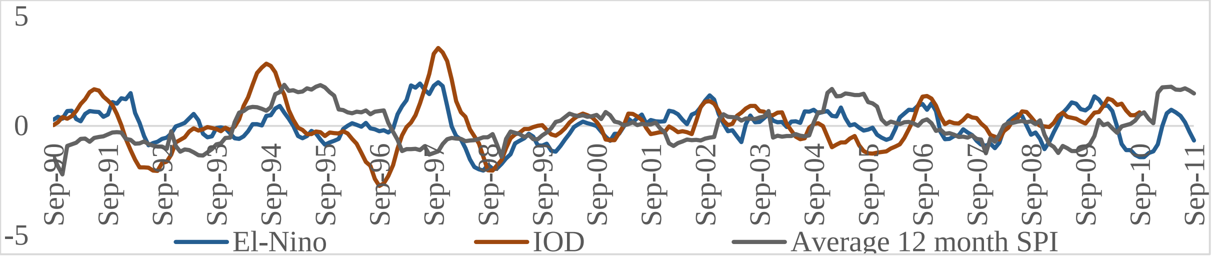


Figure 8: Comparison of SPI with ESNO and IOD

RECOMMENDATION

The research procedure is universal and can be applied to any reservoir .The parameters have to be changed according to crop type, soil type and irrigation method in WAMI model. Since the weather doesn't repeat exactly in short term and the models are sensitive to changes, each season the adoptability of past findings in IWRM have to be rechecked.

The global climatology which was analyzed for past using IOD and Nino showed a considerable change after 2000 and it was reflected in zonal climatology which has a near correlation with global climatology (Figure 8). Thus the projection of future rainfall using data beyond 2000 is needed. This has to be done as an extension to this research after developing GCM data beyond 2000.For better projection of climatology due to orographic effect, it is better to dynamically downscale the models and run the physics in of different models.

ACKNOWLEDGEMENTS

First of all I would like to express my sincerest gratitude to Associate Professor Mohomad Rasmy for supervising my research and giving me very useful advices and suggestions during my individual study. I take this opportunity to extend my salutation and gratitude to Senior Professor of Tokyo University and Director of ICHARM, Professor Toshio Koike for guiding me in this research. Herewith I thank Dr Duminda Perera who made a great support as the co-supervisor and Dr. Yoshihiro Shibuo who coordinated the theses work. My sincere thanks go to JICA, ICHARM, MLIT and Department of Irrigation, Sri Lanka for providing infrastructure and support for this research.

REFERENCES

J. P. Ponrajah , 1984 .Design of Irrigation Headwork for Small Catchments, Department of Irrigation, Sri Lanka

Project Planning Branch Department of Irrigation Colombo, 2013. Pre-Feasibility Study on Mundeni Aru River Basin

NB Guttman - 1994. Accepting the standardized precipitation index: A calculation algorithm'. Journal of The American Water Resources Association

CMIP5 - Coupled Model Inter-comparison Project Phase 5 – Overview. http://cmip-pcmdi.llnl.gov/cmip5/

Takahiro SAYAMA, Rainfall-Runoff-Inundation (RRI) Model, ver. 1.4.2. International Center for Water Hazard and Risk Management (ICHARM), Disaster Prevention Research Institute (DPRI), Kyoto University

Lei Wang, Toshio Koike, Kun Yang, Thomas J. Jakson, Rajat Bindlish, Danen Yang, 2009. Development of a Distributed Biosphere Hydrological Model and Its Evaluation with the Southern Great Plains Experiments. (Sgp97 and Sgp99), Journal of Geographical research

Khargpur, Irrigation Engineering Principles Module 03, Version 02. CE IIT

Metrology of Sri Lanka, http://www.meteo.gov.lk